Ecological Effects of the Installation of an Underground Oil Pipeline on Millipede Communities in Hocking County, Ohio

A Senior Honors Thesis

Presented in Partial Fulfillment of the Requirements for graduation *with research distinction in Entomology* in the undergraduate colleges of The Ohio State University

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ABSTRACT

The expectation of a higher number of disturbance hardy millipedes (orders Julida and Spirostreptida) in a warmer, drier disturbed area vs. a forested area is supported by previous research. This was studied in a maturing (~ 75 years old) mixed hardwood forest in Hocking County, Ohio. In 2003 the forest was disturbed by placement of an underground oil pipeline resulting in the removal of all trees within 15 m of the pipeline. The temperature in the corridor is highly variable and the subsoil is now present on the soil surface. In May 2006, twenty pitfall traps were set along a north-facing hill, half in the pipeline allowance and half in the adjacent forest. In 2006, *Cambala annulata* and members of order Julida were found in significantly higher numbers ($p<0.05$) in the forested habitat. *Abacion lactarium* (n=10) was found only in the pipeline corridor. In 2007 a second study was conducted using modifications to the 2006 trap placement. Fauna from litter samples were extracted using Berlese funnels. In 2007, *Nannaria ohionis* and *Ptoyiulus impressus* were present in significantly higher numbers in the woods. *Cylindroiulus* sp. B, *Ophyiulus pilosus*, and *Oxidus gracilis* were found in significantly higher numbers in the pipeline corridor. Soil chemistry and litter quantity were analyzed in each habitat in 2007. Litter amounts and carbon levels were higher ($p<0.05$) on the forest floor than in the pipeline corridor. These results are noteworthy in light of growing forest and soil disturbance caused by increased economic development in the region.

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INTRODUCTION

Millipede Biology

Millipedes (Class Diplopoda) are arthropods that are known throughout the world as inhabitants of moist areas with a prevalence of organic material. In temperate climates, these areas include gardens and piles of yard waste in urban areas, and forests, pastures, and agricultural fields in rural areas. In these ecosystems, the consumption of detritus is beneficial and necessary as its decomposition by macroarthropods allows microbes (fungi and bacteria, among others) in the soil to act as mineralizers. This mineralization is beneficial to other organisms such as microbes and plants. Millipedes require large amounts of calcium in their diet in order to maintain their integument which serves as protection from predators and moisture loss (Hopkin and Read 1992). Millipedes generally obtain this nutrient from the soil, decaying wood, and/or leaf litter they consume. A large source of this mineral is fungi.

Adults of the millipede species known in the U.S. vary in length from a few millimeters to many centimeters. Width can vary from 0.5 millimeters to 1.5 centimeters. Crawford's (1979) research revealed that succumbing to desiccation is a larger problem for smaller millipedes. In some cases millipedes make considerable efforts, both behavioral and physiological, to avoid moisture loss. The microclimates mentioned above are preferred because the moisture they provide assists in avoiding desiccation. In general, millipedes are not tolerant of rapid changes in microclimate which can cause sudden change in the osmolality of the haemolymph (Hopkin and Read 1992).

There are some millipedes which show tolerance for harsh climates instead of cool, damp, highly organic environments. *Orthoporus ornatus* Girard 1853 (order Spirostreptida) is the only species known to inhabit deserts in southwest North America. *O. ornatus* is exceptional because it has evolved mechanisms to tolerate sudden changes in haemolymph osmolality that other millipede groups have not. Physiologically, they are able to increase production of water-proofing hydrocarbons in the epicuticle during drought (Crawford 1979). These millipedes are able to greatly minimize the rate of transpiration during dessication up to 40 °C (Crawford 1972). There is also evidence to support the ability of these animals to actively absorb water from the air during times of dormancy underground. They also possess a hindgut capable of ion transport into and out of the haemolymph (Moffett 1975). Crawford (1979) has suggested that, in general, these mechanisms are inherent to some extent in all members of the order Spirostreptida. This supports the idea that spirostreptids that inhabit the northern United States east of the Mississippi River are capable of using some or all of the above mentioned mechanisms to survive in harsh, dry conditions.

Species in the order Julida are dominant in areas disturbed by agricultural activity and also in sun-exposed grasslands (Kime and Golovatch 2000). Kime and Golovatch (2000) found that julids are found in high proportions in hotter and drier areas of Europe including Sicily, southern Italy, Greece, Iberia, and areas that are generally subject to extreme temperature conditions. Speculations regarding the reason for this dominance vary. These millipedes have the ability to exist in relatively litterless habitats due to their ability to burrow deep into soil during adverse conditions (Kime and Golovatch 2000). Spiral coiling has been observed which, in addition to protecting the millipede from attacks, causes closure of the spiracles located at the bases of the coxae. Many julid millipedes exhibit male periodomorphosis (Enghoff *et al* 1993, Hopkin and Read 1992, Kime and Golovatch 2000) in which life is extended by the molting from a sexually mature stage into an intercalary stage where the gonopods and first pair of legs become morphologically intermediate between the mature and immature forms. This tends to occur in times of dormancy due to conditions of extreme dryness or temperature variation. Development and use of these mechanisms to survive in harsh conditions are thought to be a reason for the prevalence of order Julida in relatively litterless, arid climates.

Forested habitats can undergo a number of changes which can alter the environment for organisms residing within. While what is considered disturbance varies, it has been defined as "any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment" (White and Pickett 1985). Temperate forested habitats are known for a lack of extreme temperature variation, fertile soils and a general domination by deciduous trees (Molles 2008). Alteration of any of these characteristics could make the habitat more similar to the harsher climate types described above and could be considered disturbance to an organism adapted to the temperate habitat. The actions of humans, such as deforestation, major soil excavation and vegetation replacement, may cause more temperature variation or a change in soil quality. These could be a considered a disturbance to some organisms. These changes in habitat are the kind which I think will affect soil fauna adapted to a temperate forest and this is the main focus of this study.

Hypothesis

Numbers of millipedes belonging to the orders Julida and Spirostreptida will be higher in warmer, drier disturbed areas than in an adjacent mature forest with less temperature variation and more detritus on the ground surface. This expectation is based on Crawford's research which suggests that these groups have the ability to exploit a habitat that is less favorable to most other millipede groups studied in comparison.

Objectives

1. Compare the millipede community in the pipeline habitat to the community in the forested habitat.
2. Analyze the chemistry of the soil and the quantity of litter in each habitat.
3. Compare millipede numbers to soil chemistry data.

METHODS AND MATERIALS

Study Site Description

Research was conducted at Deep Woods Farm in Benton Township, Hocking County, Ohio (39°24.3'N 82°34.6'W) (Fig. 1). This site was originally part of an area used by the Hopewell, Delaware, Wyandot, and Shawnee people, who were expelled by the early 19th century (Riccardi and McCarthy 2003). The original (pre-1800) primary forest was mixed hardwoods dominated by oak and hickory (Riccardi and McCarthy 2003) and was cleared by European settlers for lumber and farming in the early 1800s. Various parts of the property were used for crop production and the grazing of farm animals. Agriculture was abandoned in the 1930s and a variety of habitats representing many natural communities typical of the Hocking Hills area is now present.

The forests at Deep Woods are mature, secondary-growth forests approximately 75 years old. Riccardi and McCarthy (2003) defined several forest types that exist at Deep Woods: "xeric ridgetop forest" consisting of oak and hickory on ridges, "mesic upland" consisting of beech-hemlock-maple forest on north-facing hillsides and in ravines, and "hydric floodplain" consisting of a narrow riparian forest corridor along the East Fork of Queer Creek. Mowed fields, weedy fields, and young forest are some of the various successional-stage habitats present on the property. Microhabitats are also present in sandstone outcrops, ravines with waterfalls, tree holes, and a permanent stream (Horn 2005, unpublished). Human disturbance in the form of mowed fields, a vegetable garden, mowed lawns, and ornamental plantings including exotic species is present in approximately six hectares surrounding six relatively modern buildings near the entrance to the property. In addition to this, there was selective harvest of 18 hectares of

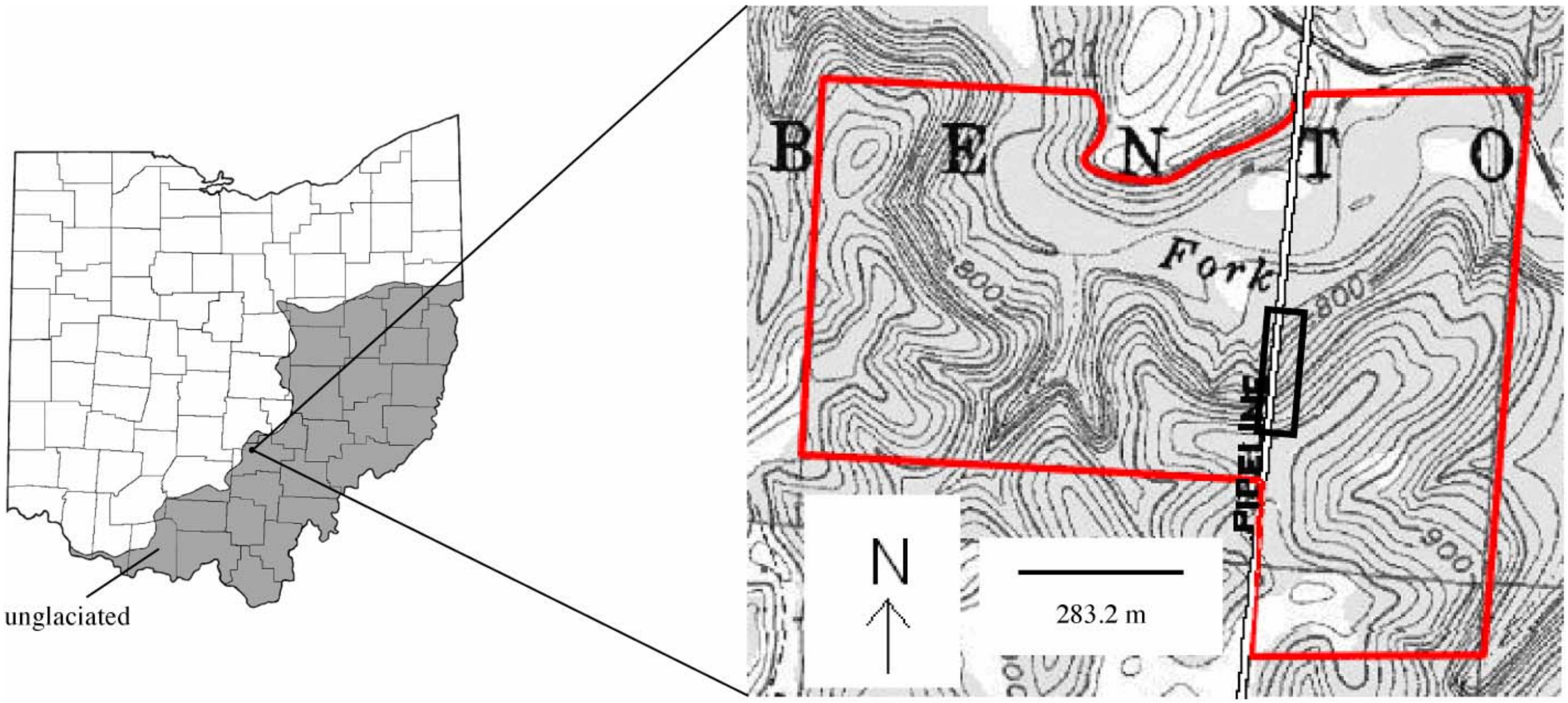

Figure 1. Map of Ohio showing the location of Deep Woods Farm, Hocking County. This area is located in the unglaciated portion of the state. The black rectangle bounds the study site.

marketable timber in 1987. In general, most recent efforts by the current owners (since 1978) have been directed toward restoration of the pre-settlement (18th century) environment (Horn 2005, unpublished).

In 2003, an underground oil pipeline was installed transecting the property north to south. This pipeline runs by the residences on the property, through a mown field, and up a medium grade hill formerly covered by mesic upland forest. As a consequence of the installation, an area 15 m to either side of the pipeline had been deforested, excavated, and back-filled. The area was replanted with a "turkey blend" mixture of vegetation (clover and timothy) intended to prevent erosion and increase the presence of wild turkeys (Fig. 2). In addition, *Panicum clandestinum* has self-seeded in the lower half of the pipeline corridor on the hill and is the most abundant species present there. This area is maintained by annual mowing. Due to the deforestation, the pipeline corridor is now subject to increased sun exposure. The former subsoil is now present in the surface layer due to back-filling. Leaf litter which was once deposited from the forest has been replaced by mosses, thatch, and surface grass-roots. A small portion of the pipeline corridor on the north-facing hill just south of Queer Creek was chosen as the "disturbed" site for the study (Fig. 1).

A mesic upland forest adjacent to the pipeline corridor site was chosen as the forested site. This area has been subject to much past disturbance and this is reflected in the age and diversity of tree species composition. The main tree species present in the forest are *Acer rubrum*, *Liriodendron tulipifera*, *Acer saccharum*, *Quercus prinus*, *Betula alleghaniensis*,

Figure 2. Downhill view of the study site from the south to the north.

Quercus alba, *Cornus florida*, *Fagus grandifolia*, *Tsuga canadensis* and *Quercus velutina* (Riccardi and McCarthy 2003 and my data).

2006 Study

Collection Method

To see if julids and spirostreptids would be found in larger numbers in the pipeline corridor, in April 2006 ten pitfall trap arrays were placed on the site (Fig. 3). A pitfall trap array consisted of two 450 mL capacity plastic cups. These were placed in the ground upright with the lip buried to the soil surface. Each trap was covered with a piece of masonite 0.093 m^2. This lid was anchored with a 0.36 m^2 piece of metal poultry netting and four 20.3 cm aluminum gutter spikes. These were located on either end of a piece of plastic garden barrier one meter long by 12 cm high used as a drift fence. This was buried approximately 2 cm into the ground on a long side and held down by four 20.3 cm aluminum gutter spikes. This barrier increased the number of individuals entering the traps by causing them to follow the barrier into the traps. No provision was made to collect information regarding the direction of travel within the habitats, only abundance and activity level (Southwood 1979). The two traps in each array were located at approximately the same elevation relative to each other. Five were placed in a north-south line on the eastern half of the pipeline corridor and aligned perpendicular to the north-south edge of the pipeline cut. Five were placed in the forest located adjacent to the pipeline corridor on the east. Trap arrays were placed at approximately 50 m intervals. Drift fences were aligned parallel to each other in both habitats. The arrays were placed on a north-facing hill and along the entire length of the hill. The approximate difference in elevation between the lowest and highest arrays was 76.2 m. Approximately 100 mL ethylene or propylene glycol was placed in the bottom of each trap as the killing and preserving agent. Traps were retrieved every seven to ten days for a total of 17 collections April to October.

Identification and Data Analysis

Trap collections were sorted in the laboratory and millipede specimens were preserved in 70% ethanol for identification. Specimens were identified using Hoffman's checklist (1999) and the key by Shear (1999) unpubl. and other keys and descriptions mentioned therein. Voucher specimens are presently held in the Deep Woods collection currently located at OSU. Data from 2006 were normalized by log transformation and analyzed by a t-test using Microsoft Excel.

2007 Study

Collection Methods

During the collections in 2006, it became apparent that great variation in moisture, vegetation, and soil texture existed along the length of the hill in the pipeline corridor. In an attempt to minimize this variation placement of the arrays was changed in 2007. Ten pitfall trap arrays (as described above) were installed with five placed in a north-south line in the pipeline corridor and five placed in the forest east and adjacent to the pipeline (Fig. 3). A similar orientation to the prior year was used (perpendicular placement of each array to the forest-corridor edge). Trap arrays were placed only in the lower third of the hill with approximately four meters between the arrays. The killing agent was ethylene glycol. Traps were retrieved every seven to ten days for a total of 19 collections April to October.

Litter samples were collected randomly (by flipping a coin to chose direction) from the area around every array in both habitats every four weeks April to September. Litter in an area of approximately 0.093 m^2 was collected within 0.61 m of the trap array in a different direction at

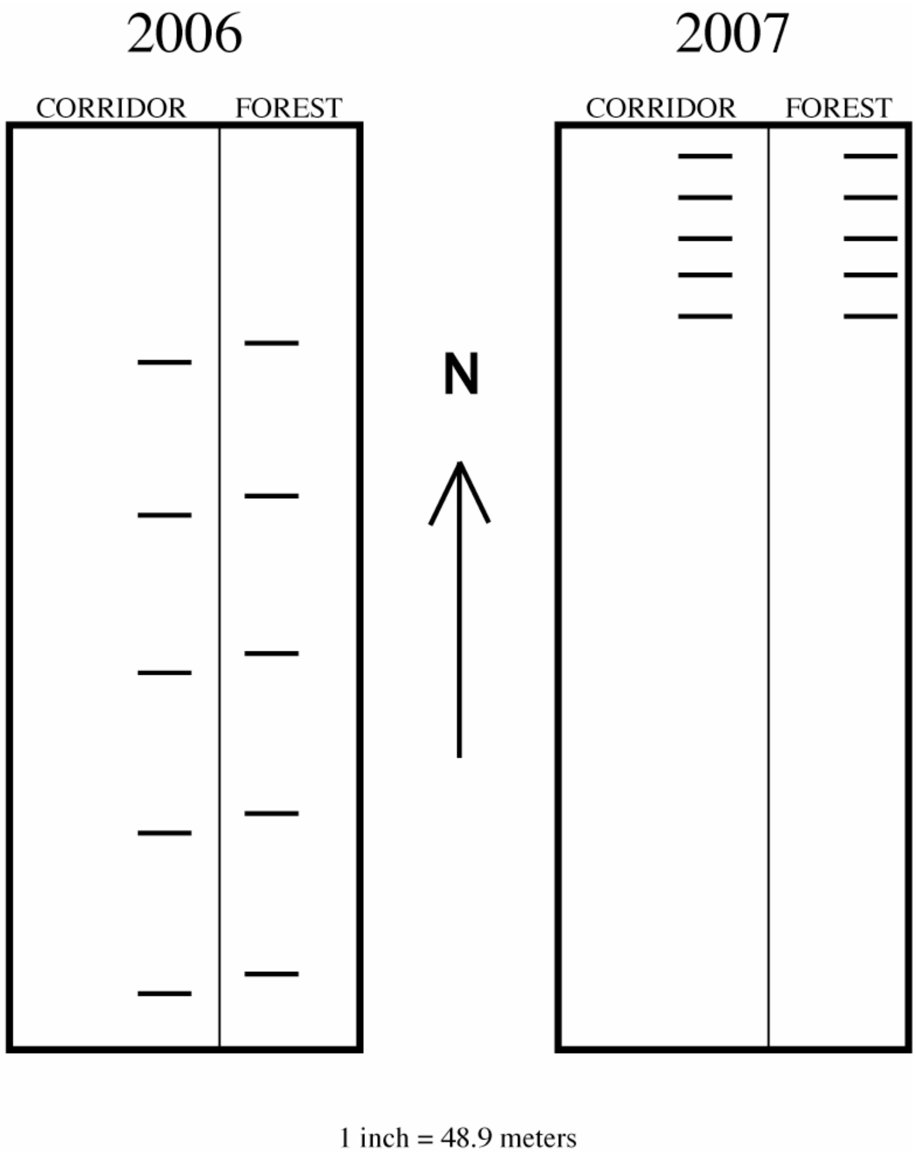

Figure 3. Transect maps for 2006 and 2007.
Lines representing trap arrays are not to scale.

each collection. Fauna were extracted at the laboratory using Berlese funnels (metal funnels lit on the inside by standard 60W/120V incandescent bulb which heats the litter placed in the funnel and forces the soil fauna through the bottom of the funnel into a container of 70% ethanol for killing and preservation). There were five litter collections in 2007 from May to September.

Soil and Litter Analyses

Chemical analyses of soil from both habitats were done in order to determine differences in the environment experienced by soil fauna. Soil cores were taken using a hand soil auger. Five cores of six 0.15 m (volume of each approximating 180.9 g/cm^3) deep were taken from within a 0.61 m radius of each array in each habitat on 15 September 20007. Additionally, two more sets of five cores were taken, one set in each habitat, at the 2006 location of the highest trap array. Samples were taken on 15 September 2007. The soil variables that were measured were compaction (kPa), total porosity (%), salinity (µS/cm), pH (1:2), active carbon (mg/kg), total carbon (%), and total nitrogen (%). The Ohio State University South Centers at Piketon, Ohio was hired to perform the soil chemistry analyses. Testing methods selected were those used as standard by the OSU South Centers under K.R. Islam (Islam 1997, Islam and Weil 1998, 2000, Bapst *et al* 2002).

Litter was sampled randomly from within a 0.61 m radius of the center of each trap array. A 0.09 m^2 frame of wire from a coat hanger was used to mark the area from which litter was collected. Six samples were collected, one from each of the arrays on 6 October 2007 plus one from each of the areas of the highest array placement in 2006 for a total of six from each habitat. These amounts were converted to overall amount per habitat (kg/hectare).

Identification and Data Analysis

Trap collections were sorted in the laboratory and millipede specimens were preserved in 70% ethanol for identification. Specimens were identified with keys by Shear (1999) unpubl. (and keys mention therein) and Blower (1985), and with Hoffman's checklist (1999). Voucher specimens are presently held in the Deep Woods Farm collection currently located at OSU. Millipede data collected from pitfall traps in the year 2007 were normalized by log transformation and analyzed by t-test using Microsoft Excel. Soil chemistry and litter data were analyzed by t-test using Microsoft Excel.

RESULTS

Millipede Data

Millipede taxa collected were approximately three times more abundant in both habitats in 2007 than in 2006 (Appendix A). Difficulties in identification of members of the order Julida arose due to the quantity of juveniles and the appearance of either a large amount of females and/or intercalary stage males. These were only identified to the order level in 2006 while other taxa were identified to genus level or lower. Millipede taxa collected in 2007 were identified to species with five exceptions, *Cleidogona* sp., *Cylindroiulus* sp. A, *Cylindroiulus* sp. B, *Narceus* sp. and juveniles and intercalary stage males of the order Julida. Numbers of millipedes collected by Berlese litter extraction were very low and no statistical analysis was completed on these data. This method of trapping did not yield any new taxa as all taxa identified were found to be groups collected by pitfall trapping (Appendix A).

In 2006, the following taxa were collected in sufficiently high numbers from pitfall traps in at least one habitat to suggest the possibility of a significant difference; *Abacion lactarium*, *Cambala annulata* (order Spirostreptida), order Julida, *Narceus* sp. and *Pseudopolydesmus serratus*. These differences were evaluated using a t-test ($p<0.05$). *A. lactarium* ($p=0.0429$) was collected in significantly higher numbers in the pipeline corridor. *C. annulata* ($p=0.00165$) and order Julida ($p=1.05 \times 10^{-6}$) were found in significantly higher amounts in the woods habitat. The differences in the numbers of *Narceus* sp. ($p=0.385$) and *P. serratus* ($p=0.682$) collected in both habitats were not significant (Table 1 and fig. 4).

In 2007, species that were collected in high enough numbers from pitfall traps in at least one habitat to suggest a statistically significant difference were *Cambala annulata* (order

Table 1.

Mean number of individuals per trap and t-test results ($p<0.05$) comparing millipede numbers from 2006 at Deep Woods Farm.

TAXON	$\text{Mean}_{\text{WOOD}}$	$\text{Mean}_{\text{PIPE}}$	T_{calc}	P value
Abacion lactarium	0	1.0	2.18	0.0429
Cambala annulata	1.7	0.2	3.70	0.00165
order Julida	7.3	2.0	7.21	1.05E-06
Narceus sp.	2.8	1.7	0.89	0.385
Pseudopolydesmus serratus	2.0	2.9	0.42	0.682

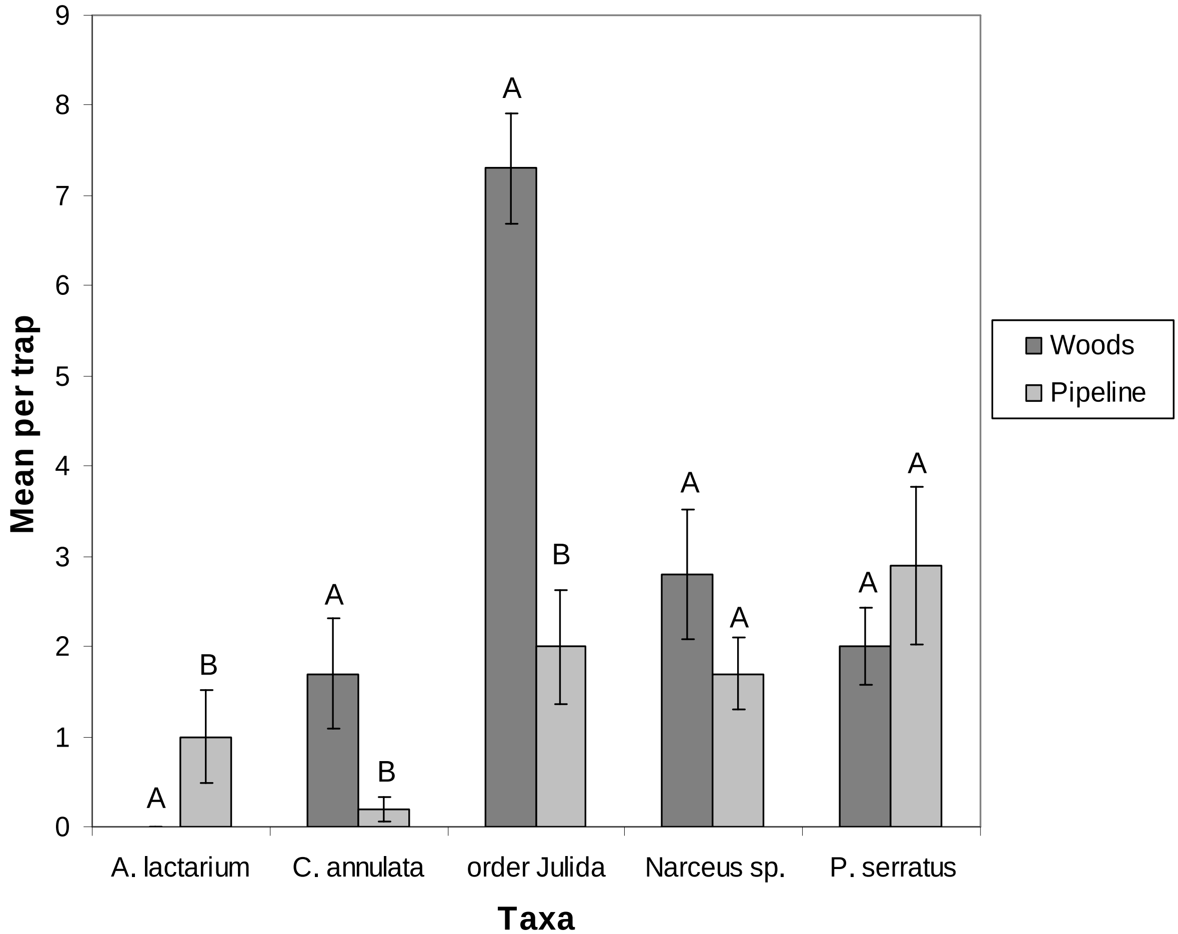

Figure 4. Comparison of millipede numbers between the Woods and Pipeline habitats at Deep Woods Farm in 2006. Columns represent mean number of a taxon per trap. Error bars represent standard error of the mean. Adjacent columns with the same letter are not significantly different.

Spirostreptida), *Cylindroiulus* sp. B (order Julida), *Nannaria ohionis*, *Narceus* sp., *Ophyiulus pilosus* (order Julida), *Oxidus gracilis*, and *Ptyoiulus impressus* (order Julida). These differences were evaluated by t-test ($p<0.05$). *Cylindroiulus* sp. B ($p=0.004$), *O. pilosus* (order Julida) ($p=0.008$) and *O. gracilis* ($p=0.021$) were found in higher numbers in the pipeline corridor. *N. ohionis* ($p=0.006$) and *P. impressus* ($p=0.005$) were found to be present in significantly higher numbers in the forested habitat. *Narceus* sp. and *C. annulata* were not collected in significantly higher numbers in either habitat ($p=0.066$ and $p=0.19$, respectively) (Table 2 and fig. 5).

An evaluation of the diversity in the communities in each year was completed by calculating a Shannon-Wiener diversity index (H) for the forested and pipeline corridor habitats. These were $H_{2006}=1.71$ and $H_{2007}=1.89$ in the pipeline corridor and $H_{2006}=1.46$ and $H_{2007}=1.53$ in the forest. The highest diversity was calculated for the community in the pipeline corridor in 2007 and the lowest in the woods habitat in 2006 with the forested habitat in 2007 and the pipeline habitat in 2006 having diversity indices in between.

Soil Chemistry and Litter Data

Soil data from 2007 were compared by t-test ($p<0.05$) (Table 3). This revealed that among the seven variables evaluated, active carbon ($p=0.0111$), total carbon ($p=0.0004$) and total nitrogen ($p=0.0086$) were significantly higher in the woods habitat than in the pipeline corridor. There were no significant differences between habitats for compaction ($p=0.4583$), total porosity ($p=0.1904$), salinity ($p=0.1471$) and pH ($p=0.2733$). Fluid and dry weight of litter were measured and converted into the unit kg/ha (Table 4). Litter data were subject to a t-test ($p<0.05$). The results showed that significantly higher amounts were present in the forested habitat ($p_{fluid}=0.0133$ and $p_{dry}=0.0064$, respectively).

Table 2.
Mean number of individuals per trap and t-test results ($p<0.05$) comparing millipede taxa collected in 2007 at Deep Woods Farm.

SPECIES	$Mean_{WOOD}$	$Mean_{PIPE}$	T_{calc}	P value
Cambala annulata	0.23	0.09	1.37	0.186
Cylindroiulus B	0	0.9	3.30	0.004
Nannaria ohionis	1.9	0	3.13	0.006
Narceus sp.	2.5	0.4	1.96	0.066
Ophyiulus pilosus	0	1.5	2.98	0.008
Oxidus gracilis	0.4	2.7	2.54	0.021
Ptoyiulus impressus	41.9	18.6	3.20	0.005

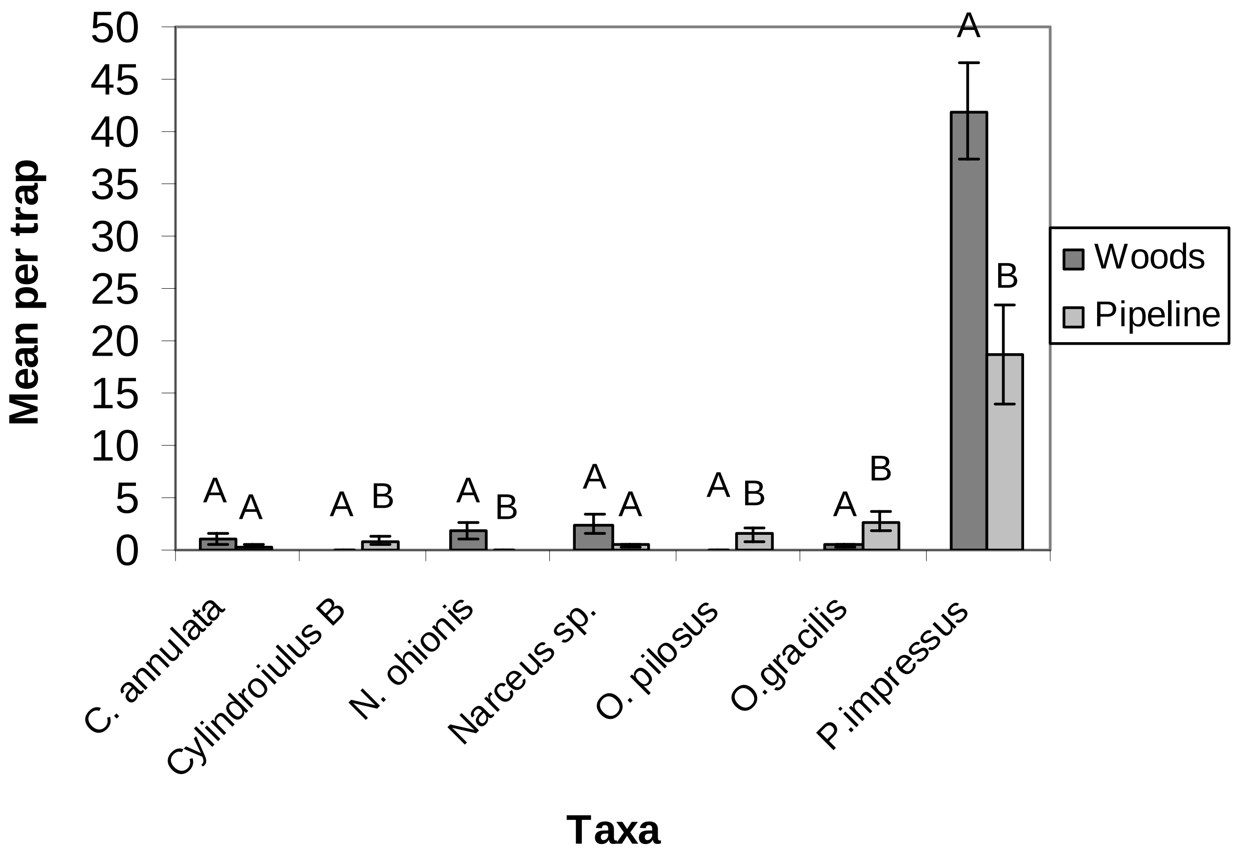

Figure 5. Comparison of millipede numbers between the Woods and Pipeline habitats at Deep Woods Farm in 2007. Columns represent mean number of a taxon per trap. Error bars represent standard error. Adjacent columns with the same letter are not significantly different.

Table 3.
Comparison of soil chemistry of samples collected from six locations in the woods and six locations in pipeline corridor at Deep Woods Farm in September 2007.

Soil variable	$Mean_{WOOD}$	$Mean_{PIPE}$	T_{calc}	P value
Compaction (kPa)	1066.3	1024.2	0.77459	0.4583
Total porosity (%)	60.020	53.913	1.39642	0.1904
Salinity (µS/cm)	77.167	63.833	1.57162	0.1471
pH	4.5850	4.4167	1.15758	0.2733
Active Carbon (mg/kg soil)	639.79	494.14	3.10805	0.0111
Total Carbon (%)	2.7000	1.1633	5.16333	0.0004
Total Nitrogen (%)	0.17833	0.11167	3.25729	0.0086

Table 4. Comparison of litter amounts from samples collected from 0.09 m^2 area from six locations in the woods and six locations in the pipeline corridor at Deep Woods Farm.

Litter amount	$Mean_{WOOD}$	$Mean_{PIPE}$	T_{calc}	P value
Fluid weight (kg/ha)	16.133	7.217	3.00333	0.0133
Dry weight (kg/ha)	13.633	5.100	3.4351	0.0064

DISCUSSION

Overall, fewer millipedes were collected in 2006 than in 2007 despite the same trapping intensity (Appendix A). The change in trap placement 2007 is likely one of the causes. In 2007 the traps were placed on the lower third of the hill where the slope is less steep than where many traps were placed in the previous year. *Panicum clandestinum* is present only in this area due to aggressive self-seeding. This is also likely a product of succession which has progressed one year further in the pipeline corridor since 2006. The result is that this part of the corridor is dense in vegetation and because of this moisture may evaporate at a slower rate. The decreased slope of the hill at this part of the site also does not allow as much moisture runoff as at the top of the hill. When trapping along the entire hill in 2006, it was apparent that the areas at higher elevation were drier and, toward the hill crest, the soil in the forest and the corridor had a rocky texture that would likely hold less water. Thus, the combination of more consistent moisture and the deposition of more organic material in the lower portion of the hill, increasing the layer of detritus are most likely reasons for the higher numbers of millipedes in this area. It is widely known that these qualities are attractive to most millipedes (Hopkin and Read 1992).

The millipede data are equivocal relative to the hypothesis that members of the order Julida and Spirostreptida would be found in significantly higher numbers in the pipeline corridor than in the forest. In 2006, individuals in order Julida, and *Cambala annulata,* the only spirostreptid at the site, were found in significantly higher numbers in the forest, not the pipeline corridor as predicted (Table 1). *P. impressus* (order Julida) was also found in the forest in higher amounts in 2007 (Table 2). However, *O. pilosus* and *Cylindroiulus* sp. B (both order Julida) were found in significantly higher numbers in the pipeline corridor in 2007. Means of *C. annulata* in 2007 were not significantly different between habitats as they were in 2006.

Millipedes from all taxa caught in both years were low and therefore the statistical test is less robust than if numbers were higher or the sample size was larger. A majority of the millipede groups which were significantly more active in the corridor habitat are invasive species known for their ability to colonize a wide range of habitats. Shear (1999) comments that there are no members of the family Julidae that are native to the eastern United States yet it is one of the most widespread families within order Julida east of the Mississippi River. *O. pilosus* and *Cylindroiulus* spp. are Julidae. Brought from northern Europe by agriculture and the deposition of ballast, these are the millipedes which are widely known pests of gardens, greenhouses, and urban landscapes. It should not be surprising that different taxa within this order were found in significant numbers in either habitat given the large presence of Julida in a large variety of habitats worldwide.

Other species were found in significantly higher numbers in the pipeline corridor but were not in either of the orders the hypothesis was intended to examine. *O. gracilis* (order Polydesmida) was found in higher numbers in the pipeline corridor in 2007 (Table 2 and fig. 5) and is an exotic species from Asia. The family Paradoxosomatidae, which includes this millipede, is indigenous to all continents except Antarctica and North America (although it is introduced here), and displays extraordinary ability to acclimate to a wide variety of habitats to become the most “widespread and abundant metazoan animal in the world” due to hardiness and the lack of natural enemies (Shelley 2007). *A. lactarium* (order Callipodida) is a species which was found in the pipeline corridor and not at all in the forested habitat in either year (Appendix A). This animal is currently thought to be native to North America and from an order which is quick moving and generally carnivorous, Callipodida (Marek and Shelley 2005). While still clearly having the body plan of a burrower (exhibits diplosegmentation) this millipede is active almost exclusively on the soil surface. The mouthparts are still clearly adapted for ingestion of dead organic material, but *A. lactarium* are known for being active carnivores which can take advantage of an ephemeral resource like fresh meat. These characteristics could explain the existence of this species in an open area with poor soil quality.

Soil and litter data collected from the forest (Tables 3 and 4) indicate that the forest floor is, overall, a habitat which not only contains significantly more detritus ($p=0.0064$) for millipede consumption, but is also host to more microbial activity than the pipeline corridor. This is specifically indicated by the amounts of carbon available in the forest habitat. The presence of higher amounts of active carbon ($p=0.0111$), total carbon ($p=0.0004$) and nitrogen ($p=0.0086$) in the forest is indicative of greater soil health. Active carbon, or available carbon, comes from microbes and other types of living organisms. A large amount of carbon signifies a larger number of living organisms in the substrate. But the true ecological impact of these organisms is their ability to process the deposited litter, not merely the existence of the carbon compounds (Bierman 1998). Soil quality is measured by the amount of organic carbon (organic matter), but this is an indication of the amount of nutrient cycling by soil organisms (Bierman 1998). The amount of nitrogen in the forest is a measurement of by-products from the processing of carbon compounds by organisms to make protein (Islam, personal comment). The larger amount indicates that more consumption and processing have occurred. The existence of this element is not as important to millipedes and other organisms as it is to plants in the same habitat. However, I could see how increased millipede presence could account for some of the increased detritus processing that the nitrogen results from. Measurements of carbon and nitrogen compounds and especially litter quantity (soil organic matter) in a habitat are accepted indicators for determining the health of a substrate (Carter 2002, Islam 1997).

Higher amounts of carbon and nitrogen compounds have been shown to correlate with increased competition and biological diversity (Bierman 1998). Shannon-Wiener diversity indices were calculated for the forested and pipeline corridor habitats in both years and these revealed higher species diversity in the pipeline corridor (H_{2006}=1.71; H_{2007}=1.89) than in the forest (H_{2006}=1.46; H_{2007}=1.53). While this seems at first to contradict the ideas discussed above, it is important to note that the Shannon-Wiener index is influenced not only by the number of species, but also the evenness in the numbers of individuals per taxon. There were nine taxa collected in both habitats in 2006 and twelve collected in each habitat in 2007. There was no difference in the taxon richness between the two habitats. However, the numbers of each taxon collected in the pipeline corridor are more even in collections made in both years than in the forest (Tables 1 and 2). In 2006, slightly more than 49% of the millipedes collected in the forest were in the order Julida. In 2007, *P. impressus* (order Julida) comprised more than 56% of the individuals found in the forest. The large proportion of these reduces the Shannon-Wiener index.

Overall, the numbers of millipedes caught in both years were very low (Appendix A). Many of these taxa were seen in single-digit numbers and this makes any calculation of diversity (or significance) a challenge to interpret because the detected presence could be a chance event and not an indication of long-term survival in the habitat. In evaluating millipede communities this is mitigated in part by the fact that these animals are generally soil bound. They normally do not travel in any other way besides walking, so accidental introduction into an unfavorable habitat by humans would be a likely explanation. It is unlikely that the millipede would travel into and have a sustained presence in the area.

Looking at the data and the statistical calculations in light of these low numbers, I think it is still unclear what effect the installation of the pipeline corridor has had on the millipede community of Deep Woods Farm and a longer-term study would need to be done in order to gain a clearer understanding of this. In evaluating the results of soil chemical analysis and organic residues (litter), the differences between the forested habitat and the pipeline corridor are apparent in the amounts of organic matter present. There may or may not be a major difference in the overall moisture and temperature between the sites as was perceived prior to the study. To ascertain the actual difference in these dynamic characteristics in both the habitats, a study should be done throughout the preferred trapping period.

Even though a statistical test revealed a significant difference in organic material present in the habitats, this difference may not be biologically significant for a majority of millipedes living in a temperate area like Ohio. Kime and Golovatch (2000) have been careful to add that, even though important adaptations have evolved which have allowed some millipedes to colonize harsher areas, their capacity for compensation when it comes to living in a habitat with inadequate conditions (little organic content, increased temperature variation and/or low moisture) is small. When studying millipede ecology and life history, this is an overriding theme (Hopkin and Read 1992, Kime and Golvatch 2000). The data provided by this study suggest that the installation of the pipeline in this portion of the Hocking Hills has altered the soil environment and amounts of organic material in the pipeline corridor. However, these changes have not had a large enough effect to greatly disrupt ecosystem, community or population structure for millipedes in this area.

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APPENDIX A:

Numbers of millipedes in 2006 and 2007

Total millipedes collected by pitfall trap at Deep Woods Farm from May-October in 2006.

TAXA		HABITAT	
Order	Species	Woods	Pipeline
Callipodida			
	Abacion lactarium	0	10
Chordeumatida			
	Cleidogona sp.	2	2
Julida		73	20
Polydesmida			
	Apheloria virginensis	1	0
	Euryurus leachii	0	1
	Nannaria ohionis	5	1
	Oxidus gracilis	1	5
	Pseudopolydesmus serratus	20	29
Polyzoniida			
	Petacerpes cryptocephalus	1	0
Spirobolida			
	Narceus sp.	28	17
Spirostreptida			
	Cambala annulata	17	2
	TOTALS	148	87

Total millipedes collected by pitfall trap at Deep Woods Farm from April-October in 2007.

TAXA		HABITAT	
Order	Species	Woods	Pipeline
Callipodida			
	Abacion lactarium	0	4
Chordeumatida			
	Cleidogona sp.	1	1
Julida	(Juveniles)	21	9
	Cylindroiulus A	27	30
	Cylindroiulus B	0	9
	Ophyiulus pilosus	0	15
	Ptyoiulus impressus	277	99
Polydesmida			
	Apheloria virginensis	6	0
	Euryurus leachii	4	10
	Nannaria ohionis	19	0
	Oxidus gracilis	4	26
	Pseudopolydesmus serratus	76	49
Polyzoniida			
	Petacerpes cryptocephalus	1	0
Spirobolida			
	Narceus sp.	21	4
Spirostreptida			
	Cambala annulata	11	3
	TOTALS	468	259

Total millipede taxa extracted by Berlese funnel from litter sampled from May-September 2007.

TAXA		HABITAT	
Order	Species	Woods	Pipeline
Chordeumatida			
	Cleidogona sp.	8	0
Julida	(Juveniles)	11	0
Polydesmida			
	Nannaria ohionis	1	0
	Oxidus gracilis	0	1
	Pseudopolydesmus serratus	1	0
Polyzoniida			
	Petacerpes cryptocephalus	1	0
	TOTALS	22	1

APPENDIX B:

Evaluation of undergraduate research experience

I have learned a number of things during my undergraduate research experience in the Department of Entomology which have been important lessons regarding my growth as a researcher. Many of these relate to the processes I chose for my experimental plan and data handling. In hindsight, I would like to have learned these lessons prior to conducting the research. First, a more thorough study of physical characteristics of the site should have been done prior to choosing this area for my experiment. It was very likely that the sites did not actually exhibit the characteristics which I attributed to them after casual observation. This lack of baseline research could have resulted in lost time and money on a long-term experiment with greater funding.

My methods of data handing I found to be inadequate for the statistical analyses I decided I needed to complete at the conclusion of the project. This inadequacy resulted from my choice at the beginning of the project to take a total count of the individuals in each millipede taxon in each year instead of recording the number of individuals in each taxon per trap per collection date. There were better, but more complex ways I could have constructed my database to organize the data. The lesson learned from this was that making the choice at the beginning of a project that you will be interested in doing the most analysis to gain the most information from your data is wise. Choosing later that this is not necessary is easier than realizing at the end that a complete recount of the organisms and a reconstruction of the data are necessary. It is also preferable in the beginning to design the database around the statistical analyses you are planning to perform at the end of the project. I did not specifically do this before the beginning of my project.

Having started my research before receiving any formal instruction in biology or ecology, I now find that the development of my hypothesis was less informed than one I would likely chose to investigate now. I have a better understanding of ecological concepts which were not influential in my thought pattern when developing my experiment. This knowledge encourages me in two ways; I know the time spent earning my degree in Entomology has been valuable to the growth of my research capabilities and it has taught to be more critical of my own assumptions in light of biological and ecological theory.